GEOPHYSICAL MODEL OF CHROMITE DEPOSITS

COX AND SINGER MODEL NO. 2a & 8a

Compilers- **A.K. Kospiri.**[1]
W.D. Heran

A. Geologic Setting

Two major deposit types are included, both hosted within mafic-ultramafic complexes; stratiform and podiform types.

Stratiform: Within cratonal, mostly Precambrian shield areas, as repetitively layered mafic-ultramafic intrusions. Layered chromite in lower intermediate zone of layered gabbro-peridotite, which may be traced for miles. Chromite occurs in massive to disseminated layers with cumulate texture.

Podiform: Magmatic cumulates in elongate magmatic pockets occurring along spreading plate boundaries; exposed in accreted terranes as part of ophiolite assemblage. Autoliths in the tectonite peridotite (alpine) usually occur within the lower part of the ophiolite complex and are highly deformed and serpentinized. Pods may lie near the transition zone below magmatic cumulates in the sequence. Ore bodies are massive to disseminated chromite surrounded by a thin dunite halo in a harzburgite host, and the ore body host contact is generally sharp.

B. Geologic Environment Definition

Remote sensing techniques may be used to detect and map ultramafic belts and intrusive complexes by overall reflectance (albedo), thermal properties, and geobotanical changes (Barrington, 1991; Longshaw and Gilbertson, 1975). The Semail ophiolite in Oman has been mapped and its units subdivided using Landsat TM data (Abrams, 1987). Ophiolite belts are characterized by aeromagnetic data as en echelon belts of short wavelength, high gradient anomalies (Heinz, 1989), and chains of narrow local positive and negative magnetic anomalies (Menaker, 1981). Aeromagnetic surveys and regional gravity data have been used to delineate the extent and shape of large layered intrusions (Blakely, 1984; Gould and others, 1985; Kleinkopf, 1985; Blakely and Zientek, 1985). Detailed gravity data have been used to estimate thickness and subsurface form of ophiolite massifs (Sharp, 1989). Detailed magnetic prospecting has helped map ophiolite sequences under sedimentary cover (Bozzo and others, 1984). Integrated ground magnetic and gravity surveys have been successful in finding and determining the size and shape of buried ophiolite massifs (Babadzhanyan, 1983). Additionally, integrated aeromagnetic, regional and detailed gravity and electromagnetic data were utilized to map the extent and structure of a layered intrusive in South Africa (Gould and others, 1985). Gravity and electrical data have helped determine horizon thickness and structure at the Bushveld complex (de Beer and others, 1987; Hattineh, 1980). Other examples of the utilization of integrated geophysical methods to aid in defining the size, shape or depth of ultramafic complexes are: the Great Dyke of Rhodesia (Weiss, O. 1940) ; ultramafic rocks in northern California (Irwin, W.P. 1962); ultramafic rocks in the Appalachian province (Zietz, I. and Bhattacharyya, B.K. 1975); Papuan ultramafic belt, New Guinea (Milsom, J., 1973); ultramafic rocks in the eastern Mediterranean (Rabinowitz and Ryant W.B.F. 1970), ultramafic rocks in former U.S.S.R. (Nepomnyashchikh, A. 1959; Moskaleva, S.V. and Zotova, I.F. 1965); Camaguey ultramafic massif, Cuba (Shablinskiy, G.N. and Damian, F. 1987) .

[1]Geophysical Enterprise, Tirana, Albania

C. Deposit Definition

For several decades integrated geophysical methods have been used for chromite exploration. Gravimetric, magnetic, electrical, electromagnetic and seismic surveys have all been applied. The literature shows exploration surveys have been carried out in the U.S.A., former U.S.S.R., South Africa, Rhodesia, Albania, Turkey, Finland, Cuba, Greece, Philippines, Yugoslavia, New-Caledonia, China, Sudan, and other countries.

Test holes were drilled on the crests of 106 gravity anomalies in Cuba. The results of drilling revealed that ten anomalies overlie deposits of chromite (Davis, W.E. et al., 1957). Gravity methods have been successfully used for the exploration of chromite in the Urals and Kazakhstan. Positive gravity anomalies due to chromite ores, as a rule, have an intensity of 0.8-1.0 mgals, their areas ranging from 0.1-0.2 km^2. Chromite orebodies at a depth of 150 m were clearly identified from gravity data (Klichnikov, V.A., and Segalovich V.I., 1970). Large chromite deposits are readily identifiable using gravity techniques even in rugged topography (Yungul, 1956). Ground magnetic surveys have had varying results. Since chromite is moderately magnetic, direct detection may only be achieved if the host rock is uniformly nonmagnetic (Hawkes, 1951). Integration of gravity and magnetic techniques have proven to be useful. A combination of refraction seismic, ground magnetic, and complex resistivity methods was found to be effective in the identification of podiform chromite deposits (Wynn, J.C., 1981, 1983). Very Low Frequency Electromagnetic (VLF-EM) have yielded good resolution in exploration for podiform chromite in Maryland (Miller, J.P.,1981). Chromite deposits in Kazakhstan were identified in boreholes by means of nuclear logging. (Karanikolo, V.F. et al., 1968).

D. **Size and shape of deposit**

In stratiform complexes groups of layers are continuous and uniform in thickness and may be traceable for miles. Podiform chromite deposits are in the form of pods, lenses, veins, tabular, pencil-shaped, disseminated schlieren, or irregular in form. Most pods are small, but large bodies are known in Kazahstan, Kempirsai; Albania, Bulqiza deposit; Philippines, Coto orebody.

E. **Physical Properties** (units)	**Deposit**	**Host rocks** Dunite	Peridotite	Serpentinite
1. Density (gm/cc)	3.0-4.6 [42,63]	2.7-3.3 [23]	2.8-3.33 [82]	2.0-2.7 [32,82]
2. Porosity (%)	0.2-3.8 [78]	0.3 [13]	0.1-0.8	2.5-10
3. Susceptibility (10^{-5} SI)	20-9502 [5,26]	30-200 [52,63]	200-3000 [52,63]	30-6000 [26]
4. Remanence (10^{-5} SI)	100-8100 [30]	10-1800 [26]	20-1300 [26]	10-9500 [30]
5. Resistivity (ohm-m)	8500 average	64000	68000	10000
6. IP Effect (%)	0.2-18 [26]	0.2-2.0	0.2-2.0	0.2-50 [26]

7. Seismic Velocity Vp (km/sec)	4.5-9.5	5.7-8.9[13]	6.2-10	4.2-4.5[13]
8. Radioelements				
K (ppm)	very low	10-900[74]	1000-10000[74]	1000[74]
U (ppm)		0.001	?	1-0.1
Th (ppm)		1-0.001	0.1	0.001

F. Remote Sensing Characteristics

The rock spectra, indicate that chromite bearing host lithologies should be distinguishable from surrounding ultramafic and mafic rocks using remote sensing techniques (Hunt, G.R. and Wynn, J.C., 1979) . Biogeochemical studies show that chromite poisons vegetation in a very distinctive manner, and the amount of serpentinization strongly controls both density and species of vegetation (Wynn, 1981). TM data were found to be extremely useful for mapping and subdividing the units making up the Semail ophiolite in Oman (Abrams, M., 1986).

G. Comments

Gravity studies in many different areas (Kazakhstan, Turkey, Cuba, Albania, Philippines, India, etc.) indicate that the gravity method is the most effective geophysical method for podiform chromite exploration. A typical podiform chromite deposit has a positive density contrast of about 0.8-1.5 gm/cc over the host rocks, which often produces recognizable gravity anomalies. Magnetic studies have been carried out by several investigators on chromite bodies world-wide. Results obtained in Turkey, Finland, Albania, India, Philippines indicate that this method may not be so discouraging as reported by some authors. Electrical and electromagnetic methods (IP, Complex resistivity, VLF-EM) have yielded good resolution in exploration tests over podiform chromite. Seismic field data appear to show strong velocity highs related to massive chromite contrasted with the surrounding, low velocity serpentinized peridotite (Wynn, J.C., 1981; Reid, A.B., and others,1980).

H. References

1. Abrams, M., 1987, Mapping the Oman Ophiolite using TM data: Proceedings of the fifth thematic conference on remote sensing for exploration geology; Mineral and energy exploration; technology for a competitive world, v. 1, p. 85-95.
2. Babadzhanyan, A.G., 1981, Geophysical studies of basic and ultrabasic massifs in the ophiolite zone near Lake Sevan (lesser Caucasus): Geophysical Journal, v. 3, no. 6, p. 890-901.
3. Banerjee, B., Dash, B.R., and Bose, R.N., 1964, Gravity and magnetic surveys for chromite in Cuttack District, Orissa: Proceedings of the 22nd International Geological Congress, India, section 2, Geological results of applied geophysics, p. 212-223.
4. Barreira, C.F., 1988, Prospeccao gravimetrica de cromita em Nova Rezende-MG, (Gravimetric prospecting for chromite in Nova Rezende, Minas Gerais): Revista Brasileira de Geofisica, v. 7, no. 1, p. 80.
5. Bhattacharya, B.B., Mallick, K., and Roy, A., 1969, Gravity prospecting for chromite at Sukinda and Sukrangi, Cuttack District, Orissa (India): Geoexploration, v. 7, no. 4, p. 201-240.
6. Bizkovsky, M., 1978, Mikrogrvimetricky pryzkum chromitoveho loziska Metaleion v Recku, (Microgravimetric exploration of the Metaleion Deposit, Greece) : Geologicky Pruzkum, p. 17-19.
7. Blakely, R.J., 1984, Boundary analysis of magnetic anomalies over a stratiform mafic intrusion; the Stillwater Complex, Montana (abs.): EOS, v. 65, no. 45, p. 871.
8. Blakely, R.J., and Zientek, M.L., 1985, Magnetic anomalies over a mafic intrusion, the Stillwater Complex: Montana Bureau of Mines and Geology Special Publication 92, p. 39-45.

9. Bodnar, J., File, M., Glova, D., and Husak, L., 1975, K problematike vyhladavania chromitovej mineralizacie geophysikalnymi metodami, (Geophysical methods of prospecting for chromite mineralization): Sbornik 6. celostatni conference geofyziku Plzen., p. 269-287.
10. Bosum, W., 1970, An example of chromite prospection by magnetics: Geophysical prospecting, v. 18, supplement, p. 637-653.
11. Bouladon, J., 1986, La chromite; un minerai toujuor recherche, (Chromite; a mineral constantly sought after): Chronique de la Recherche Miniere, 54, no. 485, p. 53-63.
12. Bozzo, E., Corrado, G., Elena, A., Faggioni, O., and Pinna, E., 1984, Magnetic anomalies and deep crustal structure along the Elba-Levanto-Ottone-Varzi Line: Bollettino Geofisica Teorica Applicata, v. 26, no. 101-102, p. 67-75.
13. Carmichael, R.S., ed., 1982, CRC Handbook of physical properties of rocks: CRC Press, Inc., Boca Raton, Florida; v. 1, 404 p.; v. 2, 345 p.; v. 3, 340 p.
14. Christensen, N.I., 1966, Elasticity of ultrabasic rocks: Journal of Geophysical Research, v. 71, no. 24, p. 5921-5931.
15. Coleman, R.G., 1971, Petrologic and geophysical nature of serpentinites: Geological Society of America Bulletin, v. 82, no. 4, p. 897-918.
16. Coleman, R.G., 1977, Ophiolites; ancient oceanic lithosphere?: Springer-Verlag, Berlin, 229 p.
17. Crenn, Y., 1953, Anomalies gravimetriques et magnetiques liees aux roches basiques de Nouvelle-Caledonie, (Gravity and magnetic anomalies related with basic rocks of New-Caledonia): Annales de Geophysique, Tome 9, no. 4, p. 291-299
18. Crenn, Y., and Metzger, J., 1952, Etude gravimetrique d'un gisement de chromite, (Gravity study in a chromite deposit: Annales de Geophysique, Tome 8, no. 3, p. 269-274.
19. Damian Febles, A., 1978, Aplicacion de los metodos para la busqueda de yacimientos cromiticos en Cuba, (Geophysical methods used for chromite exploration in Cuba): Ciencias Tecnicas ingenieria en geodesia y geofisica, 2, p. 13-23.
20. Davis, W.E., Jackson, W.H., and Richter, D.H., 1957, Gravity prospecting for chromite deposits in Camaguey province Cuba: Geophysics, v. 22, no. 4, p. 848-869.
21. de Beer, J.H., Meyer, R., and Hattingh, P.J., 1987, Geoelectrical and paleomagnetic studies on the Bushveld Complex; in Kroener, A., ed., Proterozoic lithospheric evolution: Geodynamics Series, no. 17, p. 191-205.
22. Dickey, J.S.Jr., 1974, A hypothesis of origin for chromite deposits: Geocimica et Cosmocimica Acts, v. 39, no. 6-7, p. 1061-1074.
23. Dohme-Viger, G., 1987, Geophysikalische Methoden in der chromitexploration, (Geophysical methods for exploration of chromite): University of Hamburg, 189 p.
24. Elidrissi, M.E., 1980, Geophysical investigations of cooper and chromite mineralization in the eastern Piedmont of North Carolina: North Carolina State University, 54 p.
25. Ergin, K., 1954, Gravity and magnetometer surveys for chromite ore deposits in Turkey: 19th International Geologic Congress, Algeria, C. R. sec. 9, no. 9, p. 123-130.
26.*Frasheri, A., 1991, Physical properties of chrome iron ore and ultrabasic rocks in the Albanides: In Leobener Hefte z. angew. Geophysics 2, p. 65-90.
27. Fu Hong Ru and Jiang Jiagui, 1986, Test result of borehole radiowave penetration method in the Xianggeshan chromite ore District, Xizang autonomous region Tibet (in Chinese): Geophysical and Geochemical Exploration, v. 10, no. 1, p. 57-60.
28. Ghisler, M., and Sharma, P.V., 1969: On the applicability of magnetic prospecting for chromite in the Fiskenaesset region, west Greenland: Groenlands Geologiske Undersoegekse, Rapp. no. 20, 25 p.

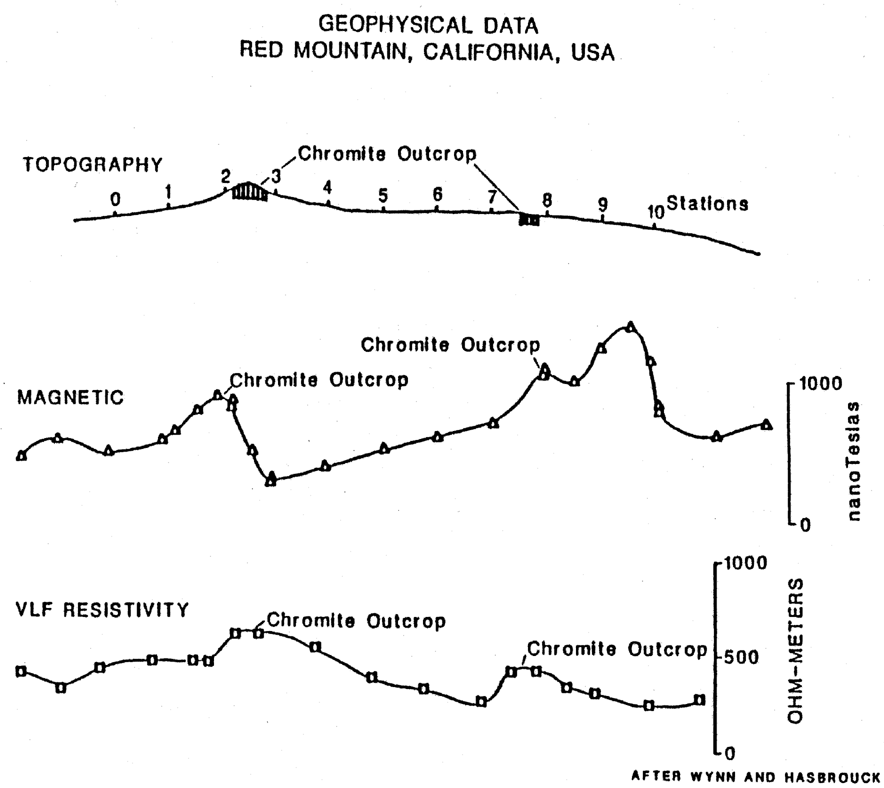
29. Gopala Krishna, G., and Radhakrishna Murthy, I.V., 1981, Magnetic survey over a chromite occurrence at Lingampet, Khammam District, Andhra Pradesh: Geophysical Research Bulletin, v. 19, no. 4, p. 277-292.
30. Gopala Krishna, G., Subba Rae, Y.V., and Radhakrishna Murthy, I.V., 1984, Results of a magnetic survey over a chromite occurrence at Gangineni, Krishna District, Andhra Pradesh: Geophysical Research Bulletin, v. 22, no. 1, p. 35-44.
31. Gould, D., Rathbone, P.A., Kimbell, G.S., and Burley, A.J., 1986, The Molopo Farms complex, Botswana; a possible target for bushveld-type mineralization?, in Gallagher, M.J., and others, eds., Metallogeny of basic and ultrabasic rocks: Institute of Mining and Metallurgy, London, p. 319-331.
32. Hammer, S., Nettleton, L.L., and Hastings, W.K., 1945, Gravimeters prospecting for chromite in Cuba: Geophysics, v.1O, no. 1, p 34-49.
33. Barrington, S.E., 1991, Use of Landsat TM data in exploration for ultramafic rock bodies in NW Ontario (abs.) : Proceedings of the Eighth Thematic Conference on Geologic Remote Sensing; exploration, engineering, and environment, v. II, p. 1123.
34. Hattingh, P.J., 1980, The structure of the Bushveld Complex in the Grablersdal--Lydenburg--Belfast area of the Eastern Transvaal as interpreted from a regional gravity survey: Transactions, Geological Society of South Africa, v. 83, no. 2, p. 125-133.
35. Hawkes, H.E., 1951, Magnetic exploration for chromite: U.S. Geological Survey Bulletin 973-A, 21 p.
36. Heinz, H., 1989, Aeromagnetic measurements in the Eastern Alps; the area east of the Tauern Window: Tectonophysics, v. 163, no. 1-2, p. 25-33.
37. Huang Ch'eng Hsung, 1959, Use of magnetic methods on ultrabasic rocks bodies (in Chinese): Geophysical Prospecting (China), no. 9, p.38-41.
38. Hunt, G.R., and Wynn, J.C., 1979, Visible and near-infrared spectra of rocks from chromium-rich areas: Geophysics, v. 44, no. 4, p. 820-825.
39. Irwin, W.P., and Bath, G.D., 1962, Magnetic anomalies and ultramafic rock in northern California: U.S. Geological Survey Professional Paper 450-B, p. B65-B67.
40. Karanikolo, V.F., Korotkova, V.A., Blyumentsev, A.M., and Feldman, I.I., 1968, Vydeleniye i otsenka khromitovih rud v razrezakh skvazhin kompleksom yaderno-geofizicheskikh metodov, (Identification and evaluation of chromite ores in borehole profiles by a combination of nuclear geophysical methods): Razvedka i Okhrana Nedra, No. 2, p. 35-41.
41. Kleinkopf, M.D., 1985, Regional gravity and magnetic anomalies of the Stillwater Complex area: Montana Bureau of Mines and Geology Special Publication 92, p. 33-38.
42.*Klichnikov, V.A., and Segalovich, V.I., 1970, The application of geophysics to exploration for chromite and tungsten; in Mining and groundwater geophysics/1967: Canadian Geological Survey Economic Geology Report 26, p. 476-484.
43. Komarov, A.G., Moskaleva, S.V., Belyayev, V.M., and Ilyina, V.I., 1962, Interpretation of magnetic fields over ultrabasic complexes; serpentinization and magnetic properties: Doklady Akad. Nauk SSSR, v. 143, p. 70-82.
44. Lakshmipathi Raju, A. 1985, Results of a magnetic study on a chromite reef at Tekuru in the eastern Ghats belt: Current Science, v. 54, no. 13, p. 628-629.
45. Langora, Ll., and others, 1989, Efektiviteti i perdorimit te metodave komplekse gjeologo-gjeofizike siperfaqesore e nentokesore per kerkim-zbulimin e mineralit te kromit, (The effectiveness of the use of complex surface and drill-hole geological-geophysical methods for the prospection of chromite): Tirane, Buletini i shkencave gjeologjike, no. 4, p. 159-171.
46. Longshaw, T.G., and Gilbertson, B., 1975, Multispectral aerial photography as exploration tool-II; An application in the Bushveld Igneous Complex, South Africa: Remote Sensing of Environment, v. 4, no. 2, p. 147-163.

47. Menaker, G.I., 1981, Ophiolite belts of the Baikal region and Transbaikal and their structural position in the crust as revealed by geophysical data: Doklady Earth Science Sections, v. 245, p. 44-46.
48. Methods of prospecting for chromite, 1964, OECD, Paris, 246 p.
49. Miletskiy, B.Ye., Stepanov, Ye.P., Samsonov, G.P., Shulgin, M.F., Feldman, 1.1., and Karanikolo, V.F. 1973, Sovershenstvovaniye metodiki poiskovo razvedochnykh rabot nakhromitovykh mestorzhdeniyakh. (Improvements in methods of exploring for chromite deposits): Razvedka i Okhrana Nedra, no. 11, p. 10-14.
50. Miller, J.P., 1987, Very low frequency electromagnetic and geochemistry in exploration for chromite mineralization, Soldiers Delight chromite district, Maryland: George Washington University, Master’s Thesis, 129 p.
51. Milsom, J., 1973, Papuan ultramafic belt; gravity anomalies and the emplacement of ophiolites: Geological Society of America Bulletin, v. 84, no. 7, p. 2243-2258.
52. Moskaleva, S.V., and Zotova, I.F., 1965, Magnetic properties of ultrabasic rocks: Doklady of the Academy of sciences of the U.S.S.R., p. 1-3.
53. Mutyorauta, J.J., 1987, High resolution seismic reflection, an exploration tool within an underground environment (example from Zimbabwe): Journal of Africa Earth Sciences, v. 6, no. 1, p. 109-115.
54. Nepomnyashchikh, A., 1959, The study of the shape and size of the Kempirsay ultabasic massif: Sovjetskaja Geologia, no. 9, p. 112-123.
55. Rabinowitz, P.D., and Ryan, W.B.F., 1970, Gravity anomalies and crustal shortening in the eastern Mediterranean: Tectonophysics, v. 10, no. 5-6, p. 585-608.
56. Radhakrishna Murthy, I.V., and Gopala Krishna, G., 1981, Magnetic survey over a chromite occurrence at Sriramagiri, Kahmmam District, Andhra Pradesh: Journal of Association of Exploration Geophysicists, v. 2, no. 1, p. 25-31.
57. Radhakrishna Murthy, I.V., 1985, Correlation between magnetic susceptibility and electrical resistivity of chromite ores: Gerlands Beitraege zur Geophysik, v. 94, no. 2, p. 148-151.
58. Rae, M.V.M.S., Gogte, B.S., and Ramana, Y.V., 1973, Partial serpentinization and its effect on the elastic properties of dunites: Geophysical Research Bulletin, v. 11, no. 4, p. 239-251.
59. Rae, M.V.M.S., and Gogte, B.S., 1972, Elasticity of some serpentinites: Geophysical Research Bulletin, v. 10, no. 1-2, p. 41-52.
60. Reid, A.B., Polome, L.G.B.T., and Green, B.W. 1980, Ultra-high resolution reflection seismology in chromite detection (abs.): Geophysics, v. 45, no. 4, p. 578.
61. Renja, A., and Lulo, A.,1990, Interpretimi sasior i anomalive magnetike DT mbi trupa xeherore kromitike. (The quantitative interpretation of the magnetic anomalies DT of chromite ore bodies): Tirane, Buletini i Shkencave Gjeologjike, no.3, p. 101-107.
62. Saad, A.H., 1969, Magnetic proprieties of ultramafic rocks from Red Mountain, California: Geophysics, v. 34, no. 6, p. 974-987.
63. Segalovich, V.I., 1970, Hromitovie mestorozhdenia Kempirsaiskovo ultraosnovo massiva. (Chromite deposits at Kempirsai ultramafic massif) pp. 349-369. In Geofizicheskie poiski rudnih mestorozhdenij (Geophysical exploration of mineral deposits): p. 610, Alma-Ata.
64. Shablinskiy, G.N., and Damian, F., 1987, Glubinnoye stroyeniye i pespektivy khromitonosnosti massiva Kamaguey. (Deep structure and prospects for chromite potential of Camaguey massif): Zapiski Lenningradskogo ordena Lenina ordena Oktyabrskoy Revolyutsii i ordena Trudovogo Krasnogo Znameni gornogo instituta im G.V. Plekhanova, no. 113, p. 80-84.
65. Shareq, A., Voinov, V.N., Nevretdinov, E.B., Kubatkin, L.V., and Gusav, I.A., 1980, The Logar ultrabasite massif and its reflection in the magnetic field (East Afghanistan): Tectonophysics, v. 62, no. 1-2, p. 1-5.

66. Sharp, B.M., Locke, C.A., and Cassidy, J., 1989, Gravity investigations of the Maungataniwha and Ahipara ophiolite massifs, Northland, New Zealand, in Geology of Northland accretion, allochthons and arcs at the edge of the New Zealand micro-continent, Sporli, B., and Kear, D., eds.: Royal Society of New Zealand Bulletin no. 26, p. 175-181.
67.* Siikarla, T., 1962, On geophysical investigations of the Kemi chromite occurrence: Finland, Commission Geologique Bulletin no.194, p.9-30.
68. Singer, D.A., Page, N.J., and Lipinl B.R., 8b, Grade and tonnage model of major podiform chromite, in Mineral Deposit Models, Cox, D.P., and Singer, D.A., eds.: U.S. Geological Survey Bulletin 1693 p. 38-44.
69. Sonido, E.P., 1963, Gravity survey for chromite over rugged topography - Coto ore body, Masinloc area, Zambales Prov. Luzon Island, Philippines: Washington University, Doctoral Thesis, 63 p.
70. Sonido, E.P., 1977, The application of geophysics to the exploration for chromite: Journal of the Geological Society of the Philippines, v. 31, no. 3, p. 17-27.
71. Sulit, J.P., 1967, Geophysical exploration and discovery of chromite ore bodies in the Masinloc mine of Consolidated Mines: The Philippine Geologist, v. 21, no. 2, p. 7-8.
72. Sumi, F., 1961, The induced polarization method in ore investigation: Geophysical Prospecting, v. 9, no. 3, p. 459-477.
73. Thayer, T.P., 1960: Some critical differences between alpine-type and stratiform peridotite-gabbro complexes: 21st International Geological Congress Report, pt. 13, p. 247-259.
74. Van Blaricom, R., ed., 1992, Practical geophysics II for the exploration geologist: Northwest Mining Association, Spokane, 570 p.
75. Vasconcelos, H.G., 1973, Contribuicao do metodo magnetometric a pesquisa de cromita (abs.). (The contribution of the magnetic method to the exploration of chromite): Sessoes Tecnicas; Geofisica, Congresso Brasileiro de Geologia no. 27, Bol. 1, p. 191.
76. Weiss, O., 1940, Gravimetric and earth magnetic measurements on the Great Dyke of Southern Rhodesia: Transactions of the Geological Society of South Africa, v. 43, p. 143-151.
77. Weiss, O., Simpson, D.J., and Paver, G.L., 1936, Some magnetometric and gravimetric surveys in the Transvaal: Union of South Africa, Department of Mines, Geol. Ser. Bull. No. 7, 27 p.
78. Wynn, J.C., 1981, Chromite geophysics; An example of synergistic geophysical exploration for industrial commodities: U.S. Geological Survey Open-File Report 81-964, 74 p.
79.*Wynn, J.C., 1983, Strategic minerals geophysical research; The chromite example: Mining Engineering, v. 35, no. 3, p. 246-251.
80. Xing Feng Tung, 1981, Useful application of borehole radio shadow technique (abs.): Australian Society of Exploration Geophysicists Bulletin, v. 12, no. 3, p. 59.
81. Yi Yongsen, 1980, Detection of high-resistivity chromite ores in an intense absorption medium using borehole electromagnetic method (abs.): 26th International Geological Congress, Resumes, v. 2, p. 753.
82.* Yungul, S., 1956, Prospecting for chromite with gravimeters and magnetometer over rugged topography in east Turkey: Geophysics, v. 21, no. 2, p. 433-454.
83. Zietz, I., and Bhattacharyya, B.K., 1975, Magnetic anomalies over the continents and their analyses: Reviews of Geophysics and Space Physics, v. 13, no. 3, p. 176-179, 210-214.

------ ----

*Papers considered to be of particular significance for exploration



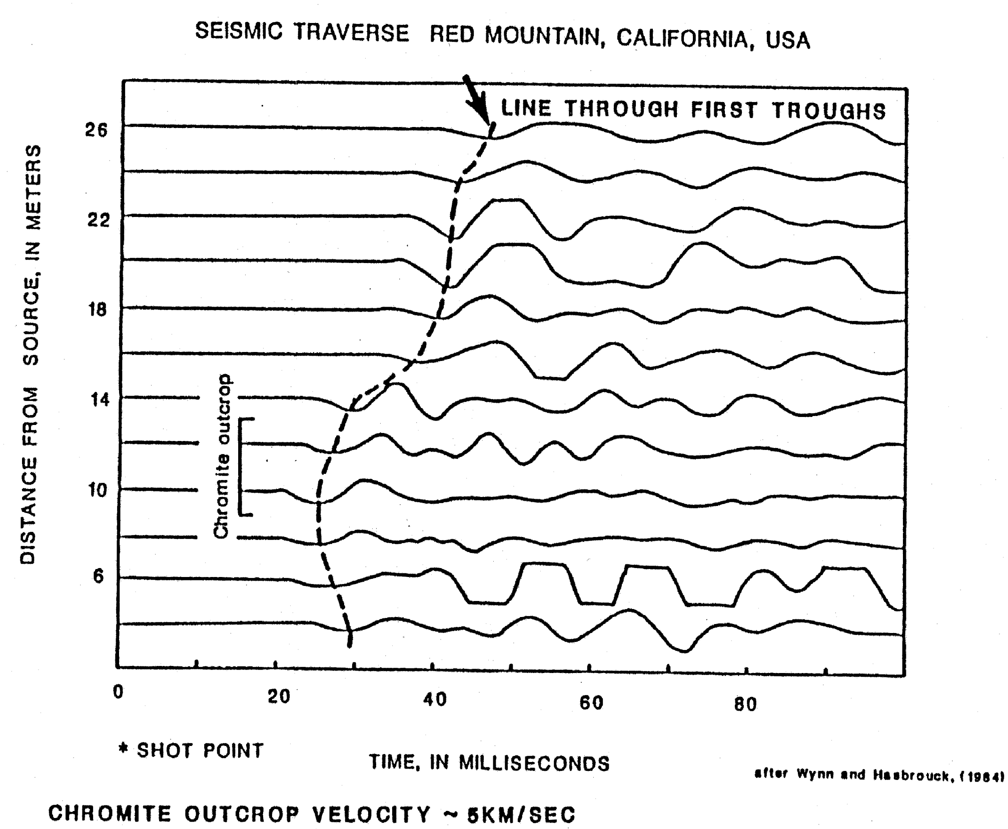


Figure 1. Magnetic data, electromagnetic data (VLF resistivity) and seismic data at the Red Mountain chromite deposit, California. (after Wynn and Hasbrouck, 1984)

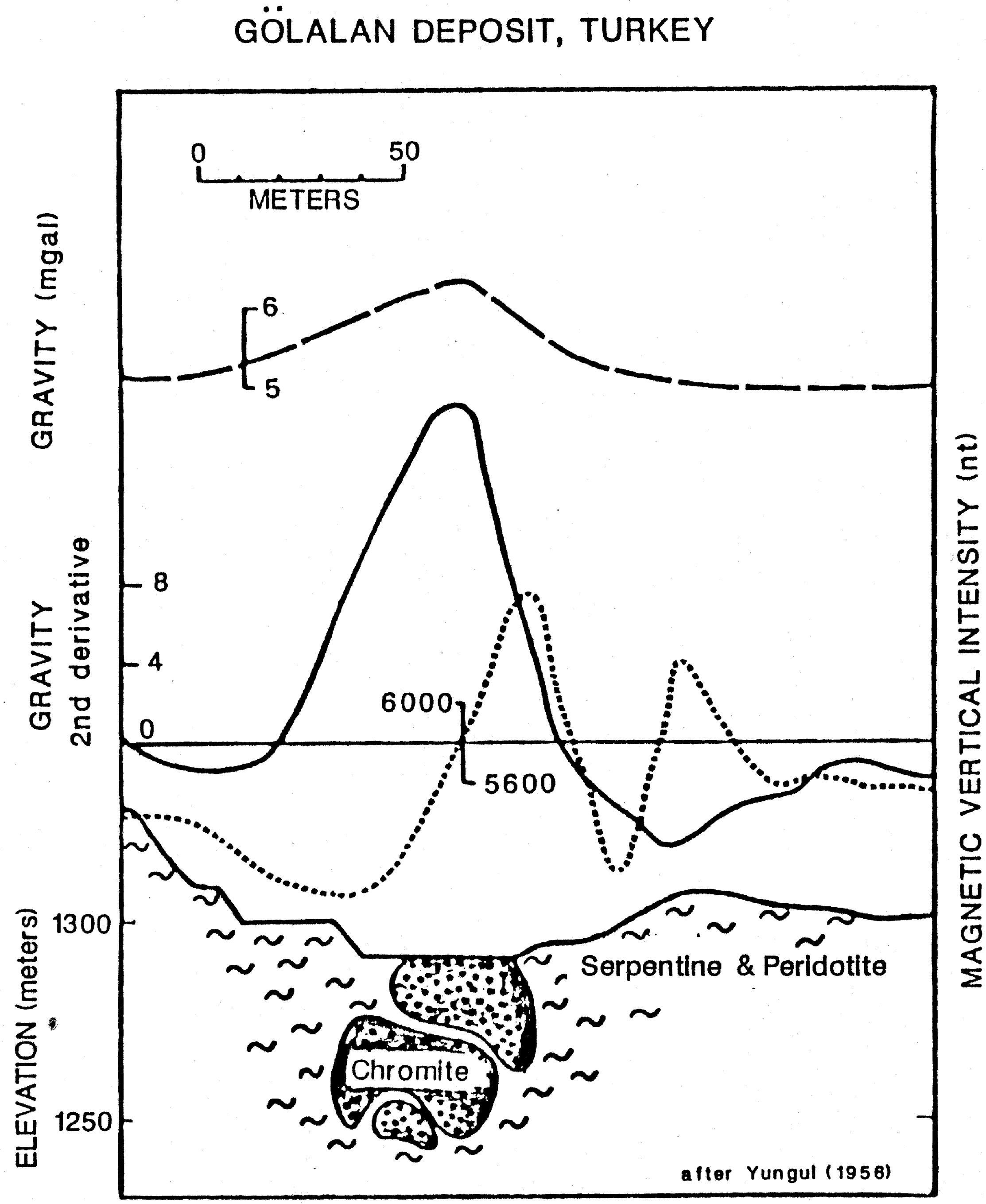


Figure 2. Bouguer gravity, 2nd derivative of gravity data, and the magnetic vertical intensity over the Golalan chromite deposit, Turkey. (after Yungul, 1956)

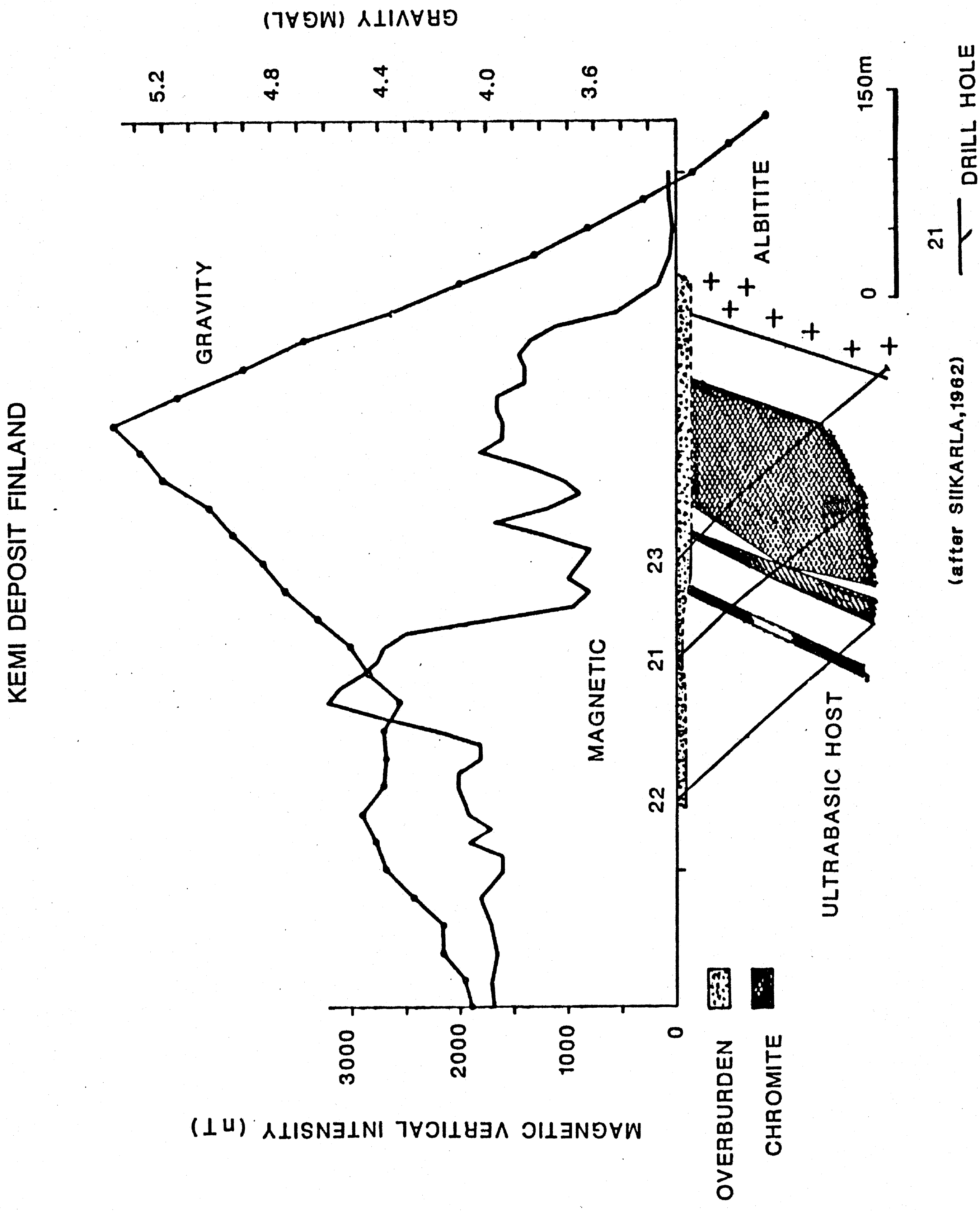


Figure 3. Bouguer gravity and magnetic vertical intensity profile data over the Kemi stratiform chromite deposit, Finland. (after Siikarla, 1962)

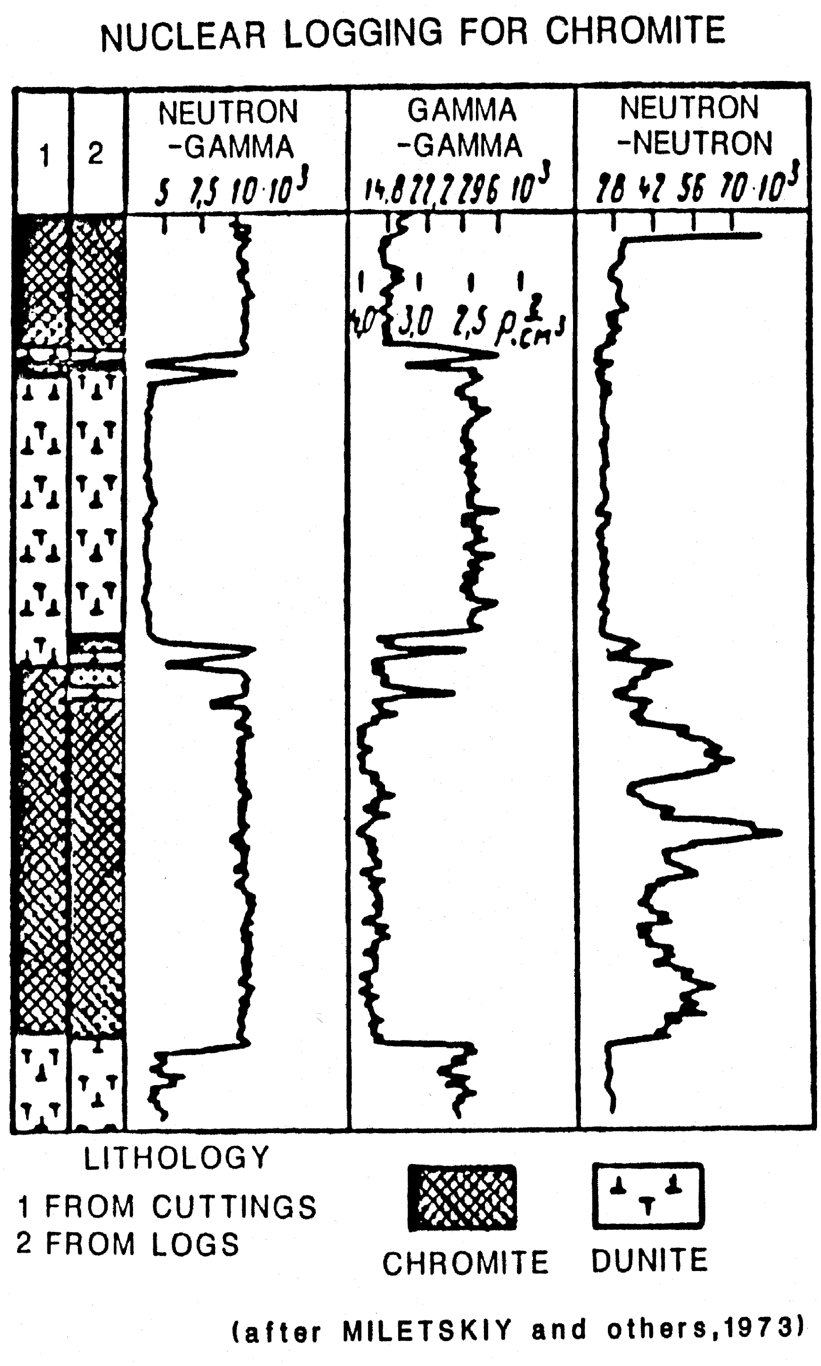


Figure 4. Borehole profiles using a combination of nuclear geophysical methods from a chromite deposit in Kazakstan. (Miletskiy and others, 1973)

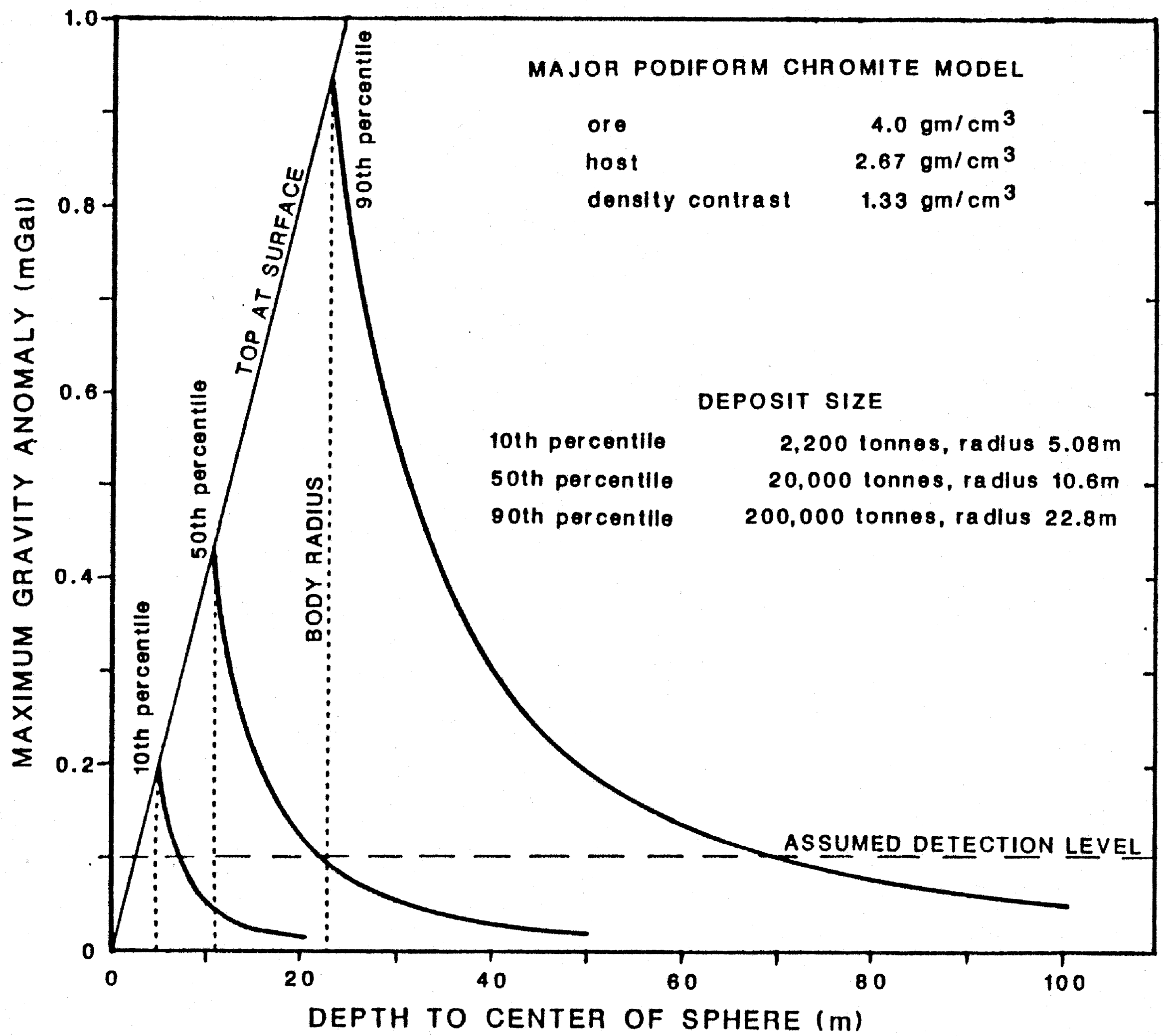


Figure 5. Graph showing the maximum gravity anomaly due to a spherical body of chromite, 4.0 grams per cubic centimeter in a 2.67 grams per cubic centimeter host as a function of depth of burial for bodies of 0.0022 M, 0.02 M, and 0.2 M tonnes. Size range of ore bodies represent the 10th, 50th and 90th percentiles of major podiform chromite deposits from Singer and others (1986).